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SUBJECT: DCATT OPTICAL SYSTEM DESIGN
DATE: 4/16/99

This document describes, in detail, the DCATT optical system design as currently baselined. This documentation consists of the following: 1) brief description, 2), design parameters, 3) optical performance using rms spot diameter, rms wavefront error at 632.8 nm (in both waves and microns), and Strehl ratio, 4) Global Coordinates. Included are drawings showing the optics in relation to the optical bench and stimulus. This memo describes both the single and double pass modes of DCATT. Separate documents will be produced for the FSM mode and the DFS mode. Listings of both the CODEV and MACOS models are included.

Let me know if there are further questions. My email address is mark.wilson@gsfc.nasa.gov, and I can be reached via phone at (301) 286-5538.

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I. Description

The basic DCATT optical system consists of the following optical groups: a source (including microscope objectives, a pinhole, and a beamsplitter BS1 used in reflection), a 45-degree fold flat, a Cassegrain telescope, an autocollimating flat mirror, the same source beamsplitter used in transmission, and a group known as the aft optics. The aft optics consists of an off-axis parabolic collimator, fold flat, deformable mirror (or conventional fold flat), a second off axis parabola to focus the beam, a fast steering mirror (or conventional fold flat), a beamsplitter used as a front surface reflector, and a final fold flat which steers the beam to the CCD detector. The collimator also produces a real pupil at a suitable location for using an off-the-shelf deformable mirror (DM). The final off-axis parabola focuses the light at the desired f/number, f/16.6. See Figure 1 for the CODEV drawing. Both off axis parabolas are identical (diameter, efl, off axis distance, etc.). The DM is a 6" diameter element from Xinetics, Corp.

Both the Cassegrain telescope and 45-degree fold flat are used in double pass mode. The beamsplitter is used in both reflection and transmission, and the aft optics are used in single pass. Beamsplitter BS1, in transmission, was assumed to have a wedge angle of 15 arcminutes, used at an angle of incidence of 20 degrees, and the material is BK7.

Another mode of the DCATT optics uses a grism, inserted in the beam between the last two reflective elements, to disperse light from a white light source to form interference fringes on the CCD. A refocusing of the CCD is required for this mode. An optical description of the grism is included below.

Off axis field points are simulated by tilt of the autocollimating flat. The CODE V optical model assumes that the rotation point is the vertex of the mirror.

The angle of tilt of the final fold flat in the aft optics (Flat2) was chosen to allow a Zygo Mark IV to fit completely on the optical bench without interference with the detector. The optical bench is a 5' by 12' bench from Newport Corp.

For determination and local control of jitter, a fast steering mirror can be implemented in the optical train. The second beamsplitter allows partial transmission of the beam (nominally 10%) to a centroid detector, baselined as a quad cell. A singlet lens is used to increase the optical throw ($\sim 4.5X$) so that an accurate determination of the centroid may be made. The beam size on the quad cell is ~ 3 mm in diameter. The quad cell must be relocated for each object point in the field (i.e. each tilt of the collimating flat).

A final mode of DCATT rotates Flat2 by approximately 180 degrees so that the focused beam is travelling in the opposite direction from nominal use. This allows an interferometer to analyze the beam, as an extra method of confirming the image quality. Nominally, this interferometer is a Mach Zender. The designer is Andrew Lowman of JPL.

II. OPTICAL DESIGN PARAMETERS

The optical parameters of this system are:

TELESCOPE

Primary (from Oak Ridge National Lab/U of Arizona)

DIAMETER	= 903 MM	(CLEAR APERTURE)
	= 910 MM	(PHYSICAL)
RADIUS	= 4000 MM	(CONCAVE)
CONIC CONSTANT	= -1	(PARABOLA)
MIRROR F/NUMBER	= 2.2	

Secondary (manufactured at GSFC)

DIAMETER	= 174.4 MM	(CLEAR APERTURE)
RADIUS	= 882.379 MM	(CONVEX)
CONIC CONSTANT	= -1.710085	(HYPERBOLA)
MAGNIFICATION	= 7.5	
F/NUMBER	= 2.3	

OVERALL TELESCOPE

F/NUMBER	= 16.6	
BACK FOCUS	= 1250 MM	(PRIMARY VERTEX TO IMAGE)
MIRROR SPACING	= 1617.637 MM	(PRIMARY TO SECONDARY VERTEX)
OVERALL LENGTH	= 2867.639 MM	(SECONDARY TO IMAGE)
EXIT PUPIL SIZE	= 193.5 MM	(DIAMETER)
EXIT PUPIL LOCATION	= 3214.3MM	(FROM IMAGE, TOWARD SECONDARY)
FOV	= 3.1656 x 2.112 ARCMIN	(TOTAL, LARGEST IN YZ PLANE)

45 DEG FOLD FLAT

DISTANCE FROM TELESCOPE IMAGE	= 450 Mm	
DISTANCE FROM PRIMARY VERTEX	= 800 MM	
CLEAR APERTURE	= 52.7 MM	(ACTIVE AREA, CIRCULAR)

BEAMSPLITTERS

MATERIAL:	= BK7	
DIAMETER (BS1)	= 38.1 MM	(Physical Diameter)
DIAMETER (BS2)	= 76.2 MM	(Physical Diameter)

AUTOCOLLIMATING FLAT

DIAMETER	= 950 MM	(CLEAR APERTURE)
THICKNESS	= 187.325 MM	
MATERIAL	= ZERODUR	

AFT OPTICS

MAXIMUM LENGTH	= 2122.3 MM	(TELESCOPE IMAGE TO DM CENTER)
MAXIMUM WIDTH	= 944.3 MM	(BOTTOM OF FLAT 1 TO TOP OF FLAT 2)

OFF-AXIS PARABOLAS (from Lambda/10 Corp.)

FOCAL LENGTH = 2032 MM
DIAMETER = 164 MM (OAP 1, OAP2 → ACTIVE AREA)
= 203.2 MM (Physical Diameter)
OFF-AXIS DISTANCE = 227 MM

FOLD FLATS (from Lambda/10 Corp.)

FLAT1 DIAMETER = 155 MM (Circular, Active Area)
= 203.2 MM (Physical Diameter)
FLAT2 DIAMETER = 13.6 MM (Circular, Active Area)
= 25.4 MM (Physical Diameter)

DEFORMABLE MIRROR (from Xinetics, Inc.)

PUPIL DIAMETER = 124 MM (Circular, Active Area)
= 150 MM (Physical Diameter)
ACTUATORS = 349 (Total number)
= 7 mm (Spacing between actuators)
= 0.004 mm (Total range of travel)
= 0.000002 mm (Step Size)

FAST STEERING MIRROR

DIAMETER = 55.8 MM (Circular, Active Area)

GRISM (from Richardson Grating Labs)

ACTIVE AREA = 18.5 MM DIAMETER
MATERIAL = BK7
CENTER THICKNESS = 4.5 MM
PRISM ANGLE = 2.464 DEG
BLAZE WL = 600 NM
BLAZE ANGLE = 2.2 DEG
GROOVE DENSITY = 35/MM
GRATING ORDER = 1
PART NO. 35-54-*-906 FROM RICHARDSON GRATING LAB.

SYSTEM

F/NUMBER = 16.6
FOCAL LENGTH = 14989.8 MM
PLATE SCALE = 0.0726 MM/ARCSEC
= 8.067 PIXELS/ARCSEC
= 0.124 ARCSEC/PIXEL
EXIT PUPIL DIAMETER = 439.2 MM
EXIT PUPIL DISTANCE = 8422.94MM (CCD To Exit Pupil, along -Z)

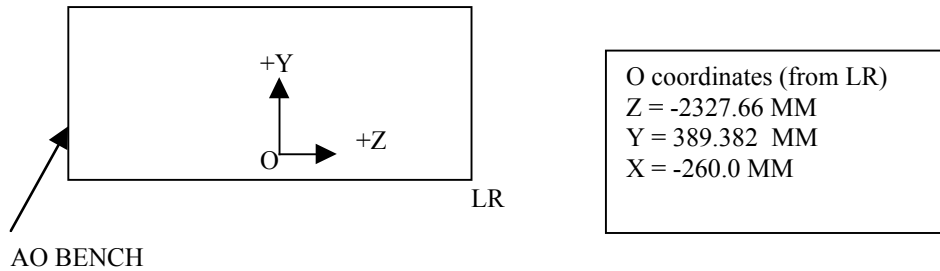
DETECTOR (from Photometrics)

NUMBER OF PIXELS = 1536 x 1024
PIXEL SIZE = 0.009 x 0.009 MM
TOTAL DETECTOR SIZE = 13.824 x 9.216 MM

III. Coordinate System

The CODE V coordinate system

Z is parallel to the Long Side of the AO Bench, +Z pointing from the telescope focus toward the OAP
Y is parallel to the Short side of the AO bench, +Y pointing from the telescope focus toward the CCD
X is perpendicular to the YZ plane, + according to right handed rule (Y into Z); +X points from the telescope focus toward the AO bench. The origin O is at a location of Z= -2327.66, Y = 389.382 MM from the lower right corner of the bench (point LR on the diagram) and coincides with the telescope focus. The optical axis of the aft optics is 260 mm above the bench top.



There are 2 other coordinate systems available for use in DCATT:

- A) The BENCH coordinate system which has the same definition of the axes as the CODEV coordinate system but is SHIFTED to the lower right corner of the bench, looking from above (i.e. the origin is at point LR as shown above).
- B) The CAD coordinate system which has the +X direction parallel to the long edge of the AO bench and the +Y axis parallel to the shorter edge of the AO bench. The +Z axis points away (upward) from the bench, in a right handed coordinate system. The origin is the same as the CODE V coordinate origin.

To translate, use the following equations:

$$+X (\text{Bench}) = +X (\text{Code V}) + 260 \quad (\text{units in MM})$$

$$+Y (\text{Bench}) = +Y (\text{Code V}) + 389.382$$

$$+Z (\text{Bench}) = +Z (\text{Code V}) - 2327.66$$

$$+X (\text{CAD}) = +Z (\text{Code V})$$

$$+Y (\text{CAD}) = +Y (\text{Code V})$$

$$+Z (\text{CAD}) = -X (\text{Code V})$$

III. GLOBAL COORDINATES (in CODE V coordinates)

7/8/98	DCATT GLOBAL COORDINATES (Z5)					
ELEMENT	XSC	YSC	ZSC	ASC	BSC	CSC
LAMP	0	-211.58222	-1236.05293	0	0	0
WLSRCL1	0	-211.58222	-914.02793	0	0	0
WLSRCL2	0	-211.58222	-885.45293	0	0	0
WLSRCL3	0	-211.58222	-853.70293	0	0	0
WLSRCL4	0	-211.58222	-816.50293	0	0	0
WLSRCL5	0	-211.58222	-788.34013	0	0	0
WLSRCL6	0	-211.58222	-737.89013	0	0	0
WLSRCFF1	0	-211.58222	-194.08013	-24.9285	0	0
SRCFF2	0	-123.03032	-268.76133	-4.857	0	0
20M PINHOLE	0	-79.25926	-216.86057	40.143	0	0
SECONDARY	-2419.78672	-1.61993	-449.99736	0	90	0.143
PRIMARY	-802.14972	-1.61993	-449.99736	0	90	0.143
AC FLAT	-2919.78672	-1.61993	-449.99736	0	90	0.143
TELFF2	0	-1.61993	-449.99736	0.143	45	0
AOBS1F	0	-0.80607	-123.83609	20.143	0	0
AOBS1B	0	1.38064	-117.87448	20.393	0	0
TELIMG	0	0	0	0	0	0
AOOAP1	0	227.08649	2019.27109	6.4165	0	0
AOFF1	0	-175.3009	479.59507	11.4165	0	0
AODM	0	308.6871	2122.29819	9.4165	0	0
AOOAP2	0	471.98529	589.0495	2.4165	0	0
FSM	0	452.27665	1941.08281	-3.5835	0	0
AOBS2F	0	537.72423	1643.09168	37.006	0	0
AOFF2	0	752.39919	1643.04702	46.5719	0	0
CCD	0	743.56672	1481.62568	3.1319	0	0
SIMFF1	0	-1.26857	-309.18669	52.6661	0	0
SIMOAP	0	464.3959	-228.73361	90	0	0
SIMFF2	0	206.77529	-431.93361	135	0	0
SIMDM	0	206.77529	-767.40061	-180	0	0
AOGRISM	0	637.72423	1643.07088	90.0119	0	0
CCD (DFS)	0	743.48286	1480.09296	3.1319	0	0
AOQUADL1	0	577.24065	1486.76133	-16	0	0
AOQUADFF1	0	604.80439	1390.63516	-36	0	0
AOQUADFF2	0	501.17469	1460.53428	-28.0011	0	0
AOQUAD	0	501.20957	585.53428	-0.0023	0	0

IV. OPTICAL PERFORMANCE

A. Single Pass Model

Lambda = 632.8 NM

X	Y (mm)	X	Y	X	Y	RMS WFE	Strehl	RMS WFE
(mm)	(mm)	(arcmin)	(arcmin)	(pixel)	(pixel)	(at 633 nm)		(Microns)
0.000	0.000	0.000	0.000	0	0	0.000	1	0
0.000	-6.909	0.000	-1.585	0	-768	0.010	0.9718	0.006328
0.000	6.903	0.000	1.583	0	767	0.010	0.9716	0.006328
-4.608	-0.001	-1.057	0.000	-512	0	0.006	0.9876	0.0037968
-4.608	-6.910	-1.057	-1.585	-512	-768	0.013	0.9589	0.0082264
-4.608	6.902	-1.057	1.583	-512	767	0.013	0.9588	0.0082264
4.608	-0.001	1.057	0.000	512	0	0.006	0.9876	0.0037968
4.608	-6.910	1.057	-1.585	512	-768	0.013	0.9589	0.0082264
4.608	6.902	1.057	1.583	512	767	0.013	0.9588	0.0082264
NOTE: NO BEAMSPLITTERS!								

Evaluated at CCD

B. Double Pass mode

X	Y (mm)	X	Y	X	Y	RMS WFE	Strehl	RMS WFE
(mm)	(mm)	(arcmin)	(arcmin)	(pixel)	(pixel)	(at 633 nm)		(Microns)
0.000	0.000	0.000	0.000	0	0	0.009	0.9973	0.0056952
0.000	-6.915	0.000	-1.586	0	-768	0.019	0.9588	0.0120232
0.000	6.908	0.000	1.584	0	768	0.012	0.9734	0.0075936
-4.608	0.000	-1.057	0.000	-512	0	0.01	0.9846	0.006328
-4.608	-6.916	-1.057	-1.586	-512	-768	0.021	0.9451	0.0132888
-4.608	6.907	-1.057	1.584	-512	767	0.013	0.9624	0.0082264
4.608	0.000	1.057	0.000	512	0	0.01	0.9846	0.006328
4.608	-6.916	1.057	-1.586	512	-768	0.021	0.9451	0.0132888
4.608	6.907	1.057	1.584	512	767	0.013	0.9624	0.0082264

See Figure 2 for spot diagrams of the double pass system.

V. CODEV ZERNIKES FOR DCATT DOUBLE PASS SYSTEM

WL = 632.8

Code V command: PMA;ZRN EXP 15;LIS N;TGR 64;GO

ZERNIKE POLYNOMIAL COEFFICIENTS

Average normalization radius			252.1989			
IMAGE CENTROID POSITION (Pixel)						
X	0	0	0	512	512	512
Y	0	768	-768	0	768	-768
Number	Value (waves at 632.8 nm)					
1	-0.0029	-0.0061	0.0182	0.0011	-0.0021	0.0222
X Tilt	2	0	0	0	0.0332	0.0333
Y Tilt	3	0.0037	-0.0459	0.0531	0.0037	-0.0459
45 deg Astig	4	-0.0193	-0.018	-0.0251	-0.0183	-0.017
Focus	5	-0.0002	-0.0034	0.0209	0.0037	0.0006
0 deg Astig	6	0	0	0	0.0003	-0.0026
	7	0	0	0	0	0
X Coma	8	0	0	0	0.0166	0.0166
Y Coma	9	0.0019	-0.0229	0.0265	0.0019	-0.0229
	10	0.0006	0.0006	0.0007	0.0006	0.0005
	11	0	0	0	0	0
	12	0	0	0	0	0
3 rd Order Sph	13	0.0028	0.0028	0.0028	0.0028	0.0028
	14	0	0	0	0	0
	15	0	0	0	0	0

Figure 1 - PERSPECTIVE VIEW OF DCATT OPTICAL BENCH LAYOUT

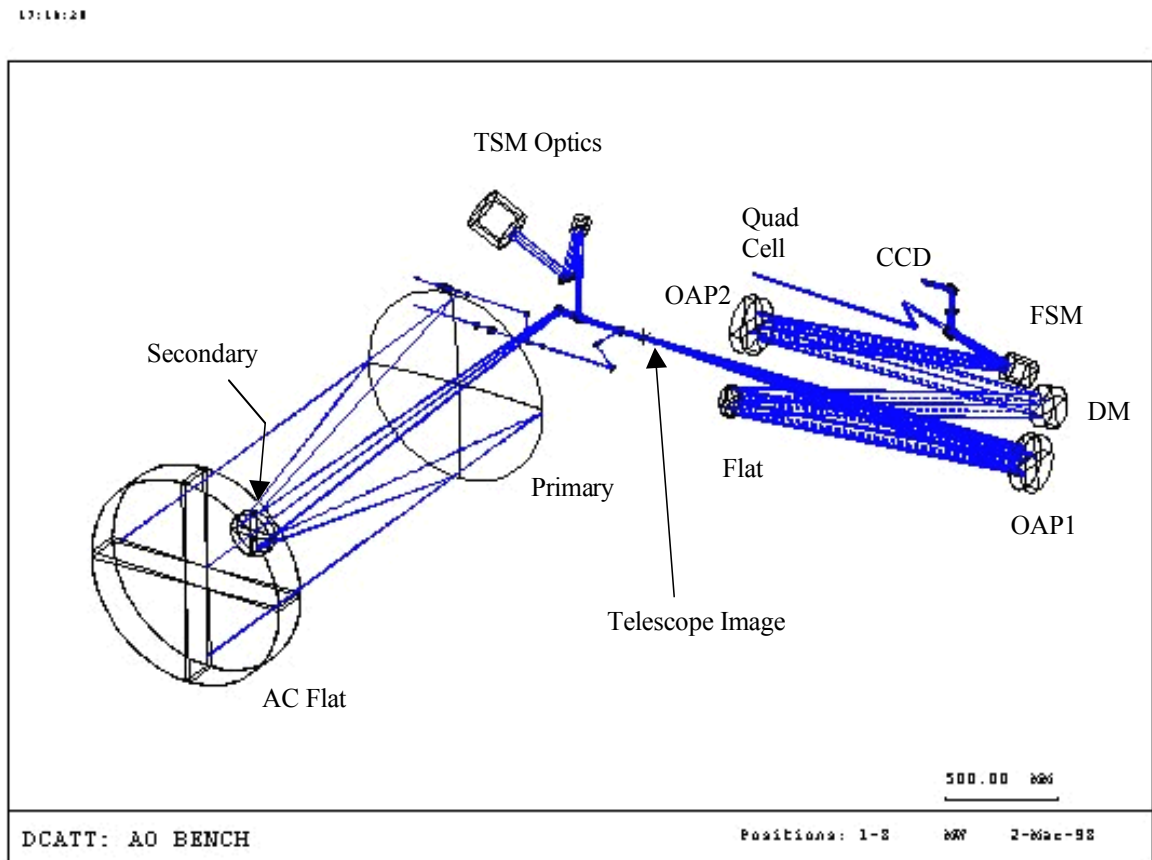
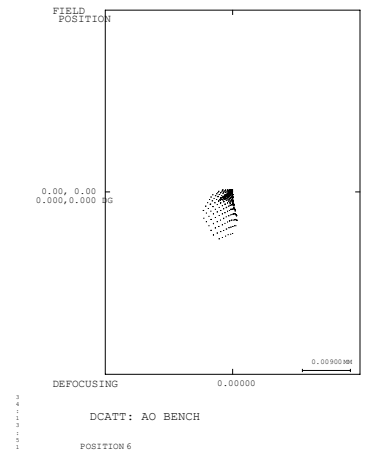
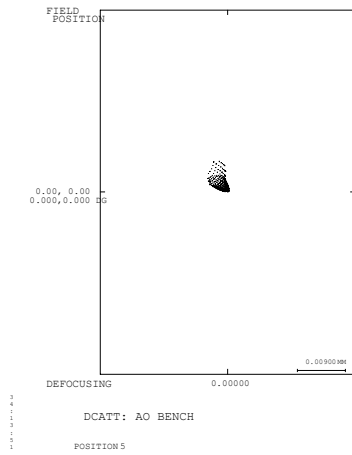
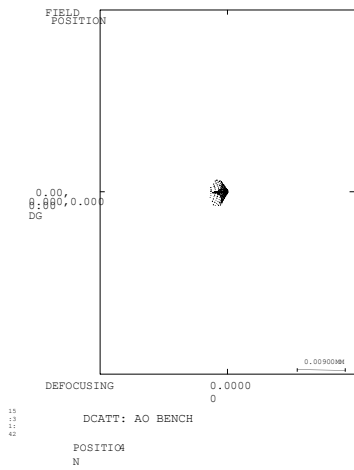
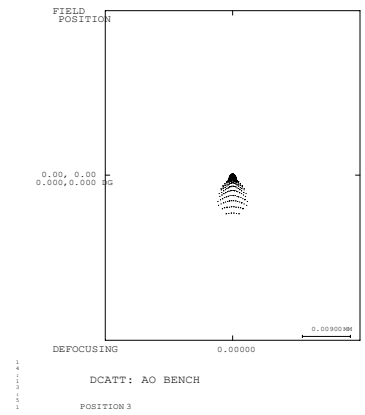
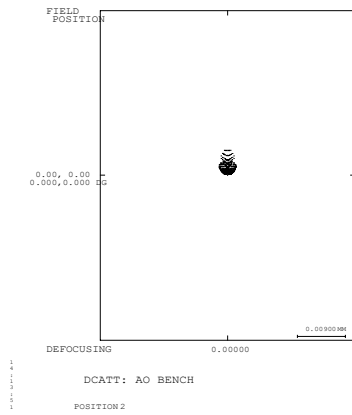
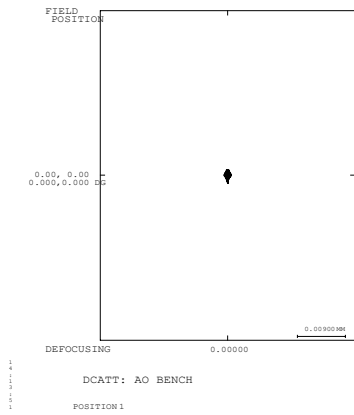


Figure 2 DOUBLE PASS SPOT DIAGRAMS AT 632.8 NM



Each horizontal bar at the lower right corner of the plots represents 1 pixel (0.009 mm). This indicates that all geometric spots are smaller than 1 pixel.